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USAARL REPORT NO. 86-12

MICROCLIMATE COOLING AND THE AIRCREW CHEMICAL DEFENSE ENSEMBLE

By

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BIOMEDICAL APPLICATIONS RESEARCH DIVISION

May 1986

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER USAARL Report No. 86-12	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Microclimate Cooling and the Aircrew Chemical Defense Ensemble		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Glenn Mitchell, Francis Knox III, Ronald Edwards, Robert Schrimsher, George Siering, Lewis Stone, Philip Taylor		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Biomedical Applications Research Division, USAARL ATTN: SGRD-UAB-CB P.O. Box 577 Fort Rucker, AL 36362-5000		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62777A 3E162777A878 AF 133
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Medical Research and Development Command Fort Detrick Frederick, MD 21701-5012		12. REPORT DATE May 1986 13. NUMBER OF PAGES 74
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution ~~Limited~~ to US Government Agencies only. Test and Evaluation; September 1985. Other requests for this document must be referred to ~~Defense Technical Information Center (DTIC), Cameron Station Alexandria, VA 22314.~~

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Presented at US Army Operational Aeromedical Problems Course, Fort Rucker, Alabama, 17 April 1985

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft NBC Protection,
Aircrew Chemical Protection,
Helicopter NBC Warfare,
NBC Protection,
Aircrew in NBC Environment
NBC Aircraft Survivability,
Heat Stress (Physiology),
Heat Stress (Psychology),
Microclimate Cooling System,
Chemical Warfare.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See Back of Page

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract

The psychological, physiological, and operational effects of sustained aviation operations in the standard US Army chemical defense ensemble were studied in six male aviators during continuous 6-day sessions in a hot, humid field environment. Standard aviation mission durations and profiles were flown in a specially-equipped JUH-1H helicopter while wearing level IV mission-oriented protective posture (MOPP IV) garments. A single case design was used to investigate the effects of microclimate cooling devices of both air and liquid medium design.

Results show that cooling is not physiologically necessary below cockpit temperatures of 29° C WBGT although subjective benefit was reported. Above 29° C WBGT cockpit temperature with closed aircraft windows and doors, microclimate cooling was necessary to avoid adverse effects of body core temperature increases. No physiologic differences were observed during use of any of the cooling devices tested. Mood and throughput changes were noted during twice-daily psychological testing. No operationally significant flight performance decrements were noted during the study due to physiologic effects, although several flights were terminated due to equipment-related medical problems. Daily serum electrolyte determinations and 24-hour urine collections revealed no significant abnormalities. Total water consumption was below estimates based on previous studies and indicates a need for reassessment of water intake policy for other than desert environments.

keyword

PREFACE

In a manuscript of this size and complexity, it may be helpful to the reader to know which author was responsible for each section of the study. The following list is for that purpose:

MAJ Mitchell - Medical safety and physiology;
Dr. Knox - Physiology (principal investigator);
MAJ Schrimsher - Safety pilot ratings;
Dr. Siering - HIMS-II analysis;
LTC Edwards - Performance Assessment Battery;
Mr. Stone - ZITA testing.

The authors would like to thank the following individuals for their sustained efforts in conducting this study under field conditions:

MAJ John Hill, CPT A. Scott Wells, CPT James Sivert, and CW4 Joseph Licina, who were safety pilots;

MAJ David Wehrly and LTC Ronald Edwards, who were medical monitors;

SSG David Campbell and SFC Richard Weber, who were the NCOICs;

SGT Roger Christiansen, who was the cardiorespiratory technician;

SSG Carolyn Ervin, SSG Clifford Lewis, SGT Deborah Rushing, SGT Jose Rosario, SP4 Susan Vorac, SP4 Henry Page, and SGT Lonnie Mills, who were medical monitors and HIMS-II operators; and

Ms. Joan Blackwell and SP4 David Foster, who conducted the psychological testing.

The authors also would like to especially thank Ms. Phyllis Morris, who spent so much time and effort typing the many drafts of this manuscript.

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INTRODUCTION

Current United States Army doctrine for the integrated battlefield depends in large measure upon aviation for support, mobility, and firepower. Concern has arisen over our ability to maintain safe and effective aviation operations in the face of the threat of opposing forces use of chemical agents (FM 21-40). Army aviation is at serious risk in the chemical environment even with innocuous agents, such as tear gas, since the ability of aviators to control their aircraft may be disrupted. In real terms, should an unprepared aircraft encounter a chemical agent, the probable outcome would be failure of the mission with loss of the pilot, crew, cargo, passengers, and aircraft. Even though the crew and passengers could conceivably don protective gear immediately upon detection of a chemical agent, the pilot could not turn his attention away from his flying tasks; the vulnerability of the pilot in this situation negates the efforts of the remaining aircrew and passengers. Therefore, pilots must don and maintain a protective posture when confronted by any chemical threat situation. The ability of pilots to operate aircraft while in the standard Army chemical defense (CD) ensemble during prolonged, operationally oriented flight schedules was the focus of this study.

Any medical or health hazards that arise from wearing a CD ensemble will have a direct impact upon survival and mission completion on the chemically contaminated battlefield. One of the most serious problems noted in previous studies (Belyavin et al., 1979; Knox et al., 1981) was the probability of heat-related illnesses. These illnesses can occur in any hot environment when body heat cannot be dissipated, and they range in severity from trivial muscle cramps to lethal heat stroke. In addition to physical stress, heat causes degradation of mental and psychomotor performance as well (Gibson and Allan, 1979; Wing, 1965; Epstein et al., 1980). Flying is a complex, integrated task, and both cognitive and psychomotor systems have been noted to be at risk of compromise in the presence of heat stress.

It also is noted that previous studies (Clanahan, 1974; Chestnut, 1969) included components of the present Army CD ensemble. These studies concluded, in part, that the ensemble could not be accepted for use as a normal work garment due to visual restrictions, heat loading when handling equipment, communications, and breathing resistance.

These concerns have prompted Aviation Systems Command (AVSCOM) to initiate a development program for microclimatic cooling. As part of this effort, AVSCOM asked the US Army Aeromedical Research Laboratory (USAARL) to investigate the psychological and physiological performance of aviators while wearing the CD ensemble during extended field operations with and without microclimate cooling vest use.

MATERIALS AND METHODS

Subjects

Seven male active duty Army aviators at the Army Aviation Center, Fort Rucker, Alabama, volunteered to act as subjects in this study. Subject number four was not included in the analysis of test results due to termination of his test week due to unseasonably cool weather conditions. The ages of the remaining six subjects ranged from 25 to 33 years (mean = 30.3; standard deviation = 2.9). Army rotary-wing flight experience averaged 786 hours (SD = 477). The subjects were required to have normal vision and hearing (AR 40-501 standards), to have no prior history of heat stroke, and to pass a physical examination conducted by a flight surgeon immediately preceding participation in the study. Individual testing for susceptibility to heat illness was not performed. Informed consent documentation is included in Appendix B.

Further medical evaluation documented each subject's physical condition through pulmonary function testing, graded maximal stress testing with determination of maximal oxygen uptake, and determination of percentage of body fat following the procedures prescribed in AR 600-9. Pulmonary tests were performed on a Gould Model 5000 IV spirometer* and the graded maximal stress test utilized a Marquette CASE Treadmill System* and USAF School of Aerospace Medicine protocol (Wolthuis *et al.*, 1977). Maximal oxygen uptake was determined using a Perkin Elmer medical gas analyzer*. Medical test results are summarized in Table 1. The first five subjects completing the study were fully

Table 1. Medical screening test summary

Subject No.	Age (yrs)	Vo2(max) ml/kg/min	Body fat (%)
1	31	40.33	19
2	33	38.02	23
3	32	37.47	20
5	25	42.65	22
6	29	45.72	20
7	32	43.55	18

* See Appendix A

heat acclimated by exercising for a total of 100 minutes each day, while wearing the CD ensemble, during the 7 days prior to their participation. The last two subjects did not acclimatize beyond their usual daily physical exercise program in gym clothing, but were in excellent physical condition.

AIRCRAFT MONITORING SYSTEMS

Aviator flight performance

The USAARL instrumented JUH-1H helicopter was used for this study. Onboard instrumentation included the Helicopter Inflight Monitoring System (HIMS-II), physiologic monitoring equipment, and environmental temperature probes. The HIMS-II was documented previously by Jones, Lewis, and Higdon (1983); and a block diagram and photograph of the system are included as Figures 1 and 2. Aircraft variables were recorded during two segments; the first segment was the heading, altitude, airspeed, and time (HAAT) maneuver and the second segment was a precision maneuver. The HAAT maneuver consisted of nine iterations of pilot

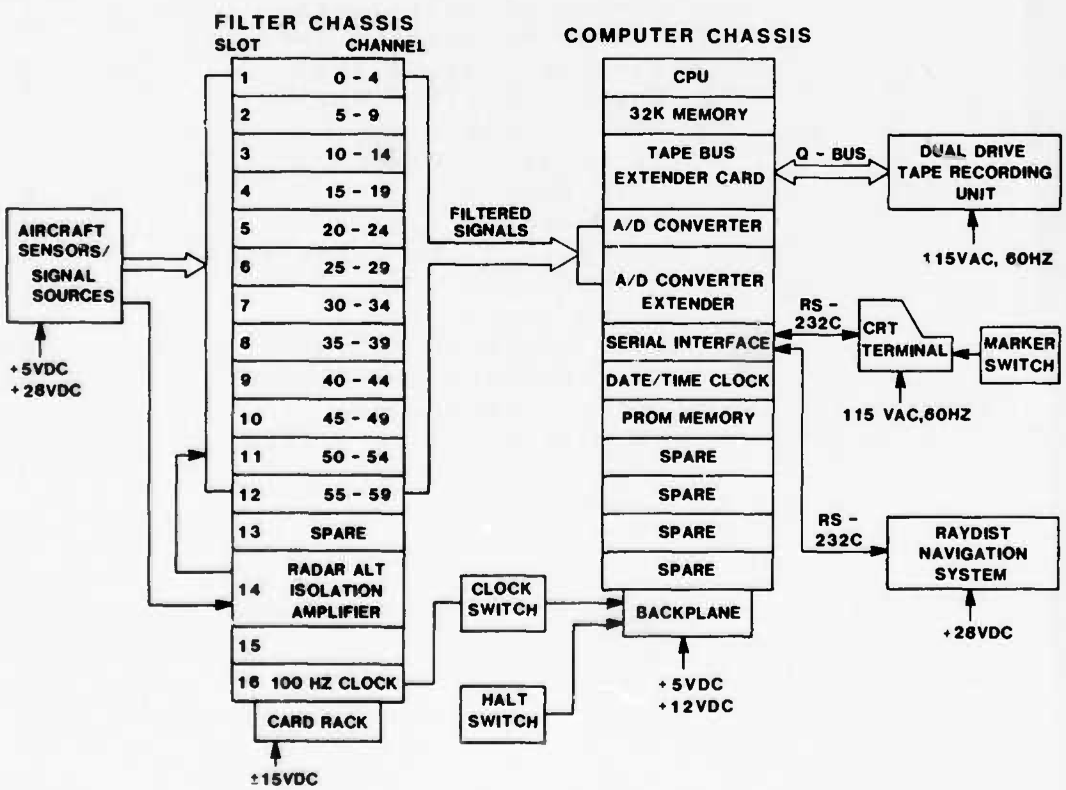

Figure 1. Block diagram of HIMS-II airborne data acquisition system.

instructions to fly a specific heading, airspeed, and altitude for a specified time. The precision maneuver was a left climbing turn between two altitudes specified by the safety pilot at a constant vertical airspeed of 500 feet per minute and 90 knots indicated airspeed. The aircraft variables measured by the HIMS-II are given in Table 2.

Table 2. HIMS-II parameters

Channel number	Variable	Sampling rate (Hz)
Measured parameters:		
1	Barometric altitude	2
2	Airspeed	2
3	Cyclic fore/aft	20
4	Cyclic left/right	20
5	Collective	5
7	Pedal	5
11	Radar altitude	2
12	Sine of roll angle	2
13	Cosine of roll angle	2
14	Cosine of heading angle	2
15	Sine of heading angle	2
16	Cosine of pitch angle	2
17	Sine of pitch angle	2
24	Vertical airspeed	2
25	Slip (ball)	2
31	Excitation	0.5
32	Wet bulb globe temperature	0.5
33	Respiration rate	1
34	Heart rate	1
35	Skin temperature (arm)	0.5
36	Skin temperature (chest)	0.5
37	Rectal temperature	0.5
38	Skin temperature (thigh)	0.5
39	Skin temperature (calf)	0.5
57	Event marker	2
59	Tape error	0.5
Derived measures:		
65	Heading	2
66	Pitch	2
67	Roll	2

Specialized programs for control movement analysis were developed by the Modeling and Simulation Branch at USAARL. Each time segment of cyclic fore-aft (FA) and cyclic left-right (LR) position data was analyzed to identify discrete movements of the control. The unit of measure for the control position was percent, with -100 being one extreme and +100 being the other. For each segment and each control, the following variables were developed:

1) The average rate of change of the identified control movements, i.e., fore-aft rate (FARATE) and left-right rate (LRRATE), measured in percentage per second;

2) The fitted total distance of cyclic movement in the flight segment normalized to 60 seconds, i.e., fore-aft distance (FADIST) and left-right distance (LRDIST), measured in percentage per minute;

3) Quality of fit, i.e., left-right quality (LRQ) and fore-aft quality (FAQ), measured as the error per sample in percentage;

4) Variables measuring rate and distance indicated the speed and amount of control movement. Fit and glitch variables are indices of data quality.

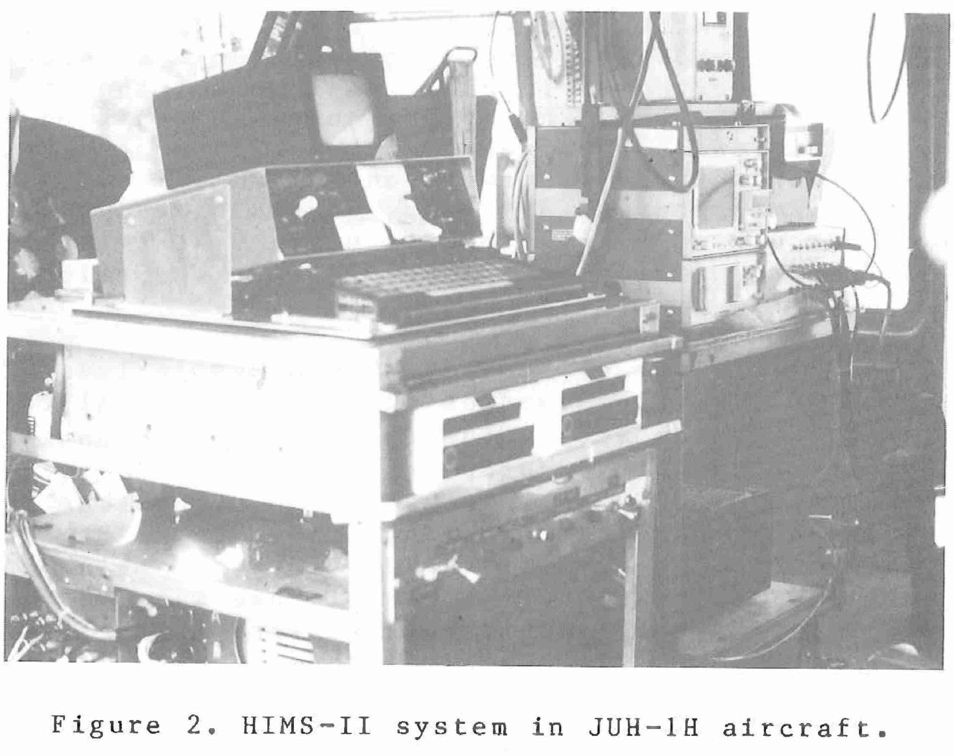

Figure 2. HIMS-II system in JUH-1H aircraft.

Safety pilot ratings of subject flight performance

In addition to recording the subject's flight performance as above, ratings were performed by the safety pilots. The rating scheme for evaluating performance on each of four flight profiles flown daily was based on Aircrew Training Manual standards (TC 1-135), and the evaluation criteria for each of the possible subtasks are shown in Appendix C. Task scoring was adjusted so that a rating of 3 (on a scale of 0 to 5) would indicate that ATM standards for that particular task were met. The lower the rating the better the subject performed.

Tasks were normalized (score for a parameter such as airspeed, altitude, etc.) by dividing the total score by the number of parameters possible. All task scores then were totaled to indicate a score for that particular flight. A low performance on one task could cause the total flight to reflect a poor performance. The four flights varied among the type and number of tasks performed. Neither an instrument approach nor nap-of-the-earth (NOE) were included in every flight.

Aviator physical performance

The subject's heart rate and rhythm were determined via continuous monitor recording on a Hittman ambulatory electrocardiographic monitor*. Skin temperatures were measured at the left upper arm, midchest, left upper thigh, and left lower calf using YSI 709 probes*. Rectal temperature was obtained by a YSI 701B probe* inserted to 15 cm. Temperature readings were performed by operator sampling at 5-minute intervals on a Tektronix 414 digital output meter*. Heart rate also was manually sampled at these intervals on the same instrument. Environmental temperatures (dry bulb, wet bulb, and globe) were determined at the same time intervals using a Reuter-Stokes WIBGET WBGT meter* with probes placed between the pilots' seats at head level.

Additional measures of subject physiology included daily determination of blood chemistries (glucose, electrolytes, BUN, and osmolarity) and complete urine collection with analyses (electrolytes, epinephrine, norepinephrine, and specific gravity). Duration of ensemble wear and documentation of fluid balance (including preflight and postflight day uniform and body weight determination on a Sauter K120 electronic balance*) and medical problems associated with ensemble use were recorded. Subjective comments by the subjects also were collected on a standard form during the outbriefing process.

Psychomotor and cognitive performance

Psychomotor and cognitive testing was conducted preflight and postflight each day. Computer administered tests were given according to a protocol developed at the Walter Reed Army Institute of Research, Division of Neuropsychiatry (Thorne *et al.*, 1983). A list of current items, short descriptions, and time to completion is found in Table 3. Subjects were oriented to the test battery and given familiarization time at the computer terminal upon arrival at the test facility the day prior to actual flight tests.

Table 3. Performance assessment battery (PAB)

Item	Description	Time
Mood scale	Self-rated description of mood scored for depression and energy levels	3 min
Reaction time	4-choice reaction time test	8 min
Logical reasoning	Visually given a relationship between letters, describe the logical order	3 min
Serial math I	Perform indicated math operation on the single-digit numbers given	3 min
Matrix	Visual/spatial task	3 min
Memory task	Recall 9 digits	3 min
Mast 6	Identification of 6 letters in a 20-letter string	3 min
Total time to complete		26 min

An additional test modality, the Zero Input Tracking Analyzer (ZITA) was utilized to determine whether or not the device could detect changes in coordination on a tracking task during the test period. This device (Walker, 1980; Walker and Walker, 1980) tests responses to first, second, and third order control of a symbol on a small LED screen through a joystick controller.

Secondary auditory or Auxiliary Distraction Tasks (ADT) were administered to the subjects on approximately 50 percent of the ZITA test trials in order to increase the subjects workload. The

ZITA was administered immediately following the PAB series above.

Both tests were administered in a standard GP-small tent with the subject seated at a table in front of a video screen and keyboard while wearing the full Mission Oriented Protective Posture (MOPP IV) uniform minus the rubber gloves to allow manipulation of the keyboard and joystick (Figure 3).

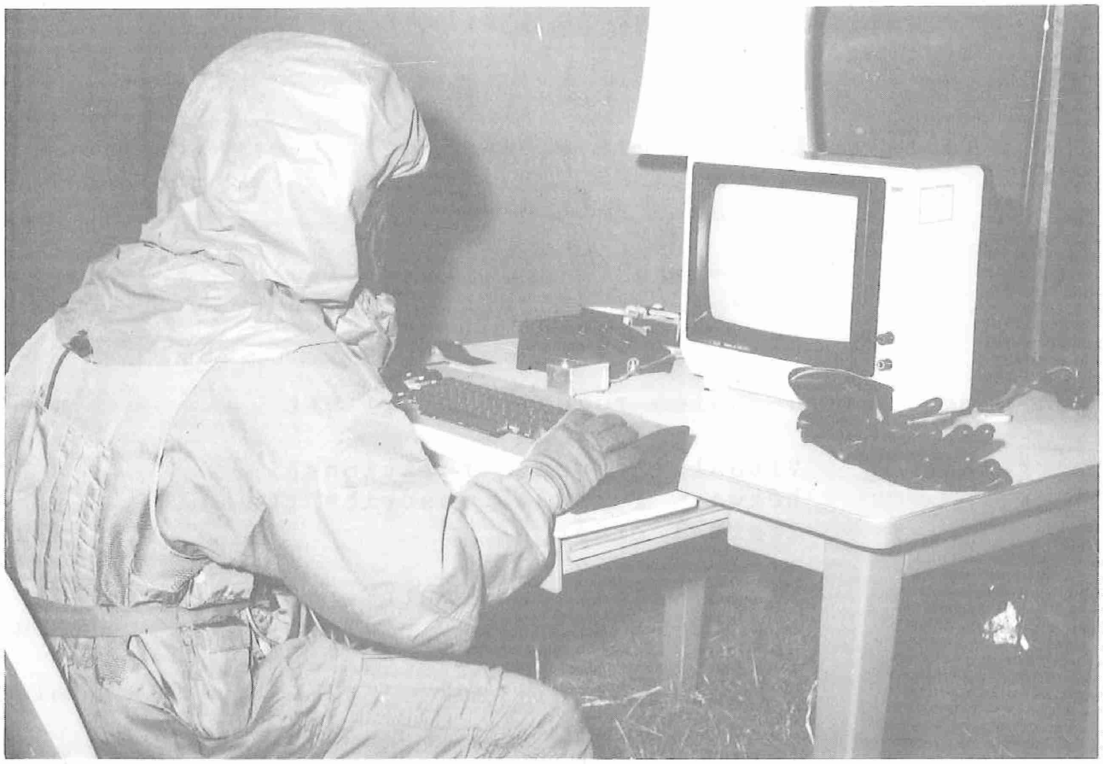

Figure 3. Performance assessment battery PAB/ZITA testing.

Chemical defense ensemble

The Army's currently fielded CD ensemble is a two-layer, two-piece overgarment with butyl rubber overboots and gloves. The overgarment is worn over the standard Nomex one-piece flight suit, and the rubber gloves are worn over the standard Nomex gloves. Head and respiratory protection is provided by the M-24 protective mask (for aviators) and the M-7 hood over the standard SPH-4 helmet (Figures 4 and 5). The outer layer of the overgarment is composed of MYCO fabric treated to repel liquids, and the inner layer is a charcoal-impregnated foam/nylon tricot laminate which absorbs chemical agents.

Figure 4. The M-24 aviation chemical defense mask.

Figure 5. The chemical defense ensemble (MOPP IV).

MISSION PROTOCOL AND TEST FACILITY

This study was conducted under simulated field operational conditions at the USAARL facility at Highfalls Stagefield (Figure 6). During daylight hours, subjects were scheduled to fly four 90-minute missions in the JUH-1H aircraft as well as to receive premission briefings and perform preflight and through flight checks on the aircraft per checklist (Figure 7). No rearming or refueling tasks were performed by the subjects. MOPP IV level was maintained during the period from breakfast to the end of the final daily PAB and ZITA test period. During the evening hours, the subjects were allowed to relax in the field tent while wearing MOPP I level protection (garments only; no gloves, boots, or mask). Breakfast and supper were provided as Meals-Ready-to-Eat (MREs), and midday intake was limited to a flavored electrolyte and glucose solution provided by Natick Laboratory. Water was allowed _ad lib._. The scheduled daily routine is illustrated in Table 4.

Figure 6. Highfalls stagefield facility.

Subjects were tested individually for a period of 6 continuous days. Flight profiles included low level, nap-of-the-earth (NOE), confined area operations, instrument approaches, and other tactical situations such as reconnaissance missions. The subjects always flew the instrument approaches and alternated between flying and navigating the NOE and low level routes. The longest NOE distance was approximately 20 kilometers. Additional flight maneuvers (HAAT and precision maneuvers), which utilized the HIMS-II flight data recorder, were designed to test pilot control and performance.

Table 4. Typical daily schedule

0600	
0630	Wake up; clean up; breakfast
0700	Monitoring equipment hook up; MOPP IV
0730	
0800	PAB/ZITA testing
0830	
0900	Preflight check; plan mission I
0930	
1000	Mission I
1030	
1100	Refuel; plan mission II
1130	
1200	Mission II
1230	
1300	Refuel; lunch; plan mission III
1330	
1400	Mission III
1430	
1500	Refuel; plan mission IV
1530	
1600	Mission IV
1630	
1700	PAB/ZITA testing
1730	
1800	Daily debriefing; shower
1830	
1900	MOPP I; dinner
1930	
2000	Free time
2030	
2100	Sleep

Each subject also was fitted with a microclimate cooling vest for use during part of the study. Three designs were tested: (1) an airflow vest (Figure 8) using a refrigerant

Figure 7. Full preflight check in MOPP IV.

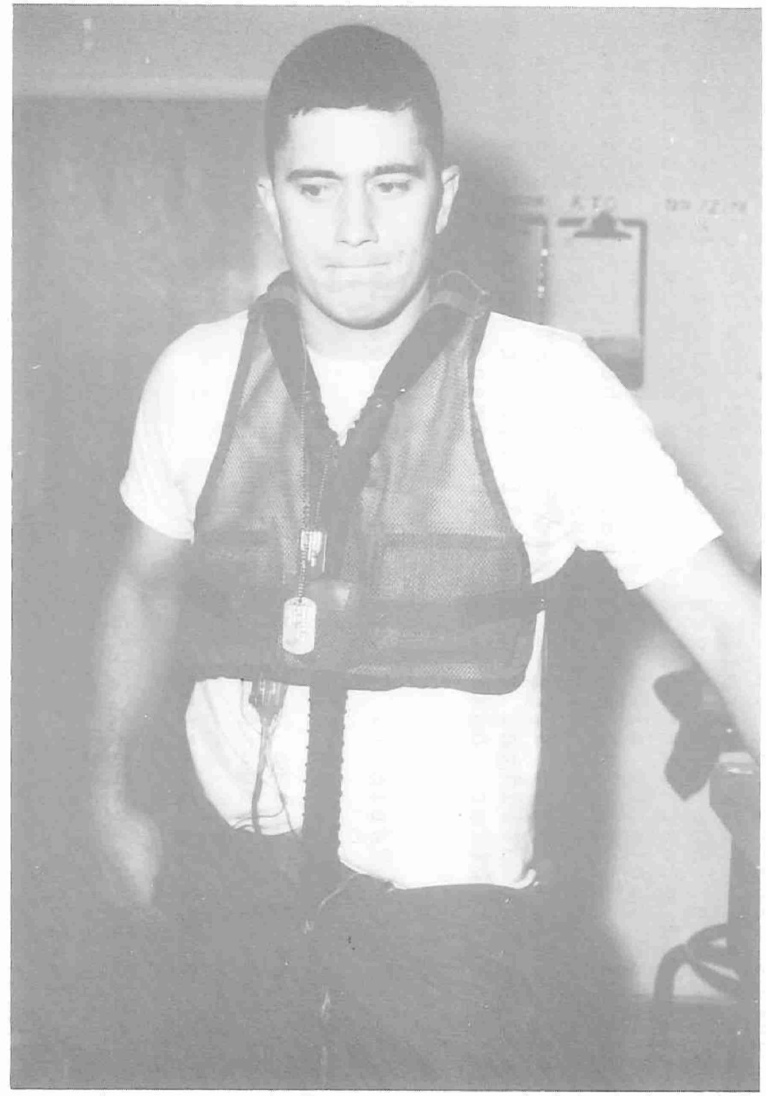

Figure 8. Airflow cooling vest.

cooling unit (Figure 9); (2) a liquid medium vest and refrigerant unit (Figures 10 and 11); and (3) the same vest as in (1) above, but powered by a small thermoelectric heat pump (Figure 12).

Each vest was worn under the Nomex flight suit and over the undershirt of the subject. Each subject wore one vest type. A standard skull cap was worn with the air flow vests while a cooled skull cap was part of the liquid vest assembly. The air flow vest (approximately 5-10 cfm flow at less than ambient temperatures) was supplemented with air flow to the M-24 mask through the filter intake at approximately 3 cfm. The cooling vests were connected only to their respective power units while the subjects were in the aircraft, not while they were conducting preflight inspections, between flights, or while taking the PAB and ZITA tests.

Although originally planned as a balanced single case design, constraints of weather and cooling system availability forced changes in the overall methodology. The actual schedule of cooling vest use, the type used, the number of missions flown each day, and the reason for terminating the day are shown in Table 5.

Table 5. Actual number of missions flown

Subject	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6	
1	NC	3*	NC	4	A1	2#	A1	4	A1	2#	NC	4
2	NC	3*	NC	4	A1	4	A1	1@	A1	4	NC	3*
3	A1	4	A1	4	NC	4	NC	2#	A1	3#	A1	3#
5	NC	3*	NC	4	LQ	4	LQ	4	NC	2*	NC	2*
6	NC	3*+	NC	2*+	LQ	4+	LQ	4+	NC	4	NC	2*+
7	NC	2*+	NC	3*+	A2	3!+	A2	3@+	NC	4	NC	2*+

* Terminated for medical condition
\# Terminated for injury by equipment
@ Terminated for weather conditions
! Terminated for equipment problems
\+ Flown with helicopter doors closed

NC = No vest
A1 = Air vest 1
A2 = Air vest 2
LQ = Liquid vest

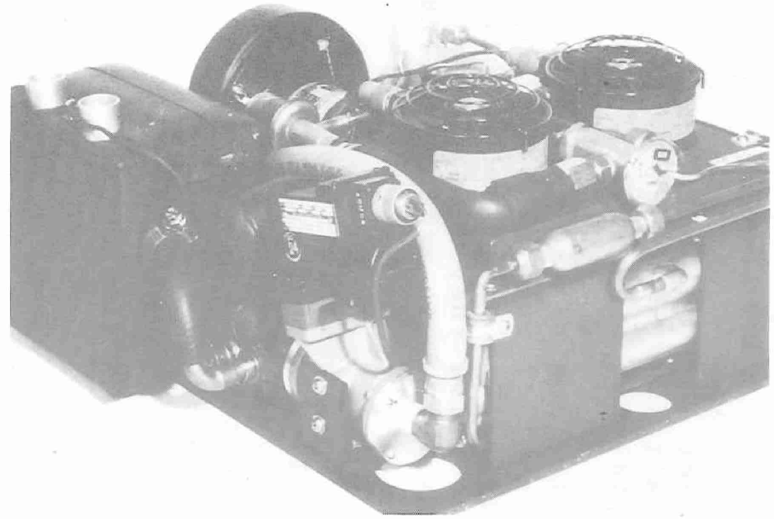

Figure 9. Airflow refigerant cooling unit.

Figure 10. Liquid cooling vest.

Figure 11. Liquid coolant unit.

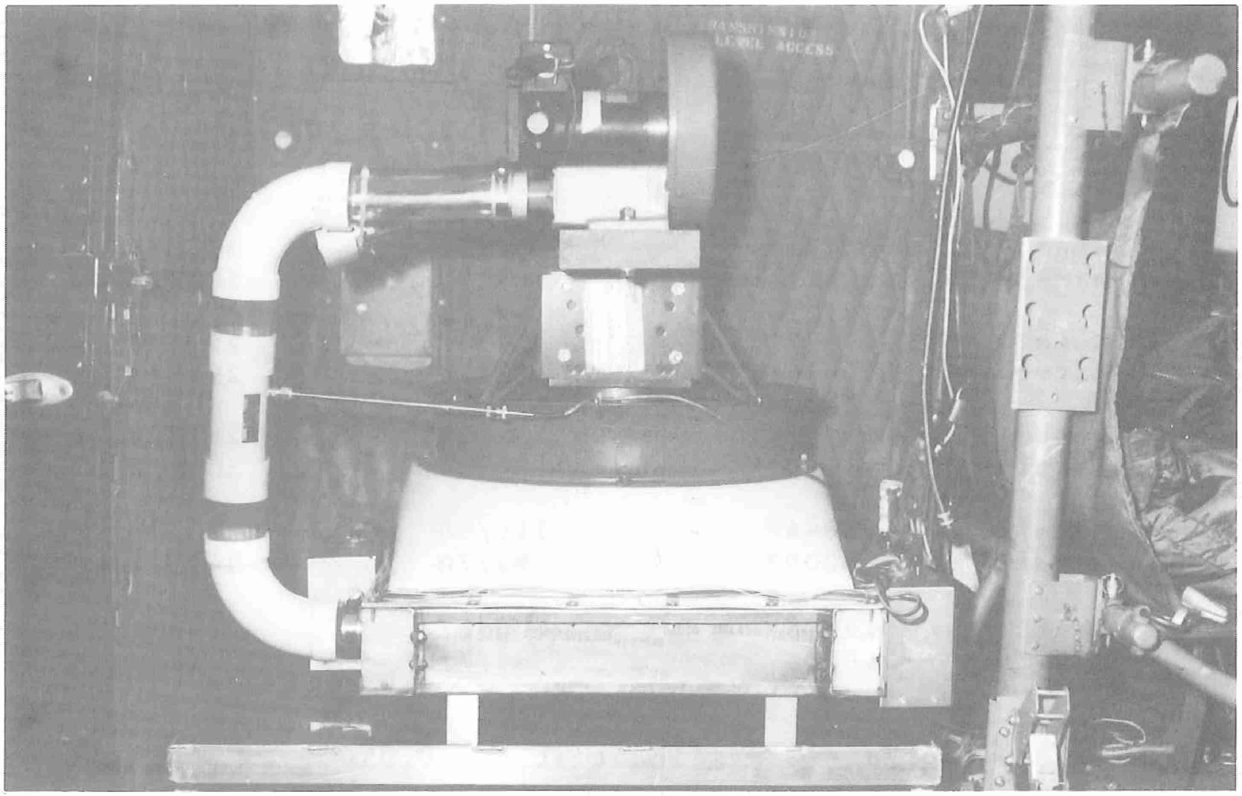

Figure 12. Thermalelectric pump.

It should be emphasized that this study was not designed to directly compare or contrast different microclimate cooling systems.

RESULTS

Physiologic performance

A. Cardiovascular system (Table 6)

Regression analysis revealed statistically significant correlations between heart rate and cockpit WBGT without use of microclimate cooling. The correlations improved with increasing average cockpit WBGT, as seen with the later subjects. One regression was significant during cooling vest use, but the slope derived was lower than values obtained for the no-vest condition. Stressful situations, such as the development of nausea, were associated with random, transient increases in heart rate for all temperatures and cooling vest types. Heart rate did not exceed 120 beats per minute for more than 5 minutes in any case. No significant cardiac rhythm disturbances were noted at any time during the study.

Table 6. Correlation of heart rate vs WBGT with and without cooling

Sub-ject	Vest	Correlation (R)	Pulse (max/mean)	WBGT (max/mean)
1	None	0.3485*	142/94	33.8/24.5
	Air-1	-0.0766	110/92	32.1/25.7
2	None	0.4258*	125/97	37.8/27.6
	Air-1	0.0606	97/83	30.7/27.2
3	None	0.1332	119/89	29.4/26.1
	Air-1	0.0614	117/78	29.8/25.4
5	None	0.5198*	120/91	29.8/26.3
	Liquid	-0.1182	100/69	30.1/25.9
6	None	0.6094*	116/90	33.2/28.9
	Liquid	0.4209*	94/70	34.3/29.3
7	None	0.7508*	100/82	31.9/28.3
	Air-2	-0.0055	89/71	34.6/30.3

Note: * Significant at $p < 0.05$

B. Thermoregulation (Table 7)

Without microclimate cooling, rectal temperature was significantly correlated with cockpit temperature (see Table 6 for cockpit WBGT temperatures). When microclimate cooling was not in use, the regressions performed for lower average cockpit temperatures resulted in smaller slopes compared to those for higher average WBGT. With all microclimate cooling systems tested, rectal temperature correlated with WBGT with small regression slopes and did not attain statistical significance under any environmental conditions encountered. Skin temperatures varied widely depending upon direct exposure of individual sensors to direct sunlight, moisture, and flowing air.

Table 7. Regression of rectal temperature (RCT) by WBGT with and without cooling

Subject	Vest	Correlation (R)	RCT (max/mean)	Slope
1	None	-0.4027*@	38.6/36.8	-0.121
	Air-1	-0.0498	37.6/37.2	-0.006
2	None	-0.1586*	38.2/37.7	-0.013
	Air-1	0.0647	37.9/37.3	-0.017
3	None	-0.2037*	38.4/37.6	-0.031
	Air-1	0.0996	38.4/37.4	-0.023
5	None	-0.3326*	37.7/37.2	-0.042
	Liquid	0.1926*	37.7/36.9	-0.041
6	None	0.5277*	38.5/37.7	0.143
	Liquid	0.2691*	37.7/37.1	0.025
7	None	0.8108*	38.4/37.5	0.184
	Air-2	-0.4346*	37.8/37.2	-0.035

Note: * Significant at $p < 0.05$
@ Equipment problems on Day 1

C. Fluid and electrolyte balance

Daily weight changes for each subject and his equipment are displayed in Table 8. Body loss is the difference between successive morning nude weights, and uniform gain are the differences between morning and end of flight day weights for all uniform components. Daily intake and output of fluids also are shown. Data are given only for the first 5 days of each test period since the last day was terminated in the afternoon and did not allow 24-hour weight change and intake/output determinations. "Other losses," as indicated in Table 8, including evaporated sweat and respiratory loss, is the difference between measured daily weight gains (oral intake and body weight gain) and losses (urine loss and uniform gain). An estimate of average daily total sweat outputs with and without microclimate cooling for each subject can be calculated as the sum of other loss and uniform gain. These estimated sweat losses show no statistically significant differences between outputs with and without microclimate cooling. Daily blood chemistries and counts were all within normal limits and showed no significant changes for any subject. Urine specific gravities showed large variations between specimens consistent with alternating periods of relative fluid deficit and replacement.

Table 8. Fluid balance summary

Subject No.	Vest type	Oral intake(ml)	Body gain(g)	Urine output(ml)	Uniform gain(g)	Other loss(ml)
1	None	2971	-445	1007	375	2033
	Air-1	3243	873	1145	410	814
2	None	3230	-690	470	605	2845
	Air-1	2392	1316	570	235	514
3	None	4080	-365	1522	680	2243
	Air-1	3488	1017	1807	723	586
5	None	2792	-137	590	347	1992
	Liquid	2925	160	1273	845	647
6	None	3288	-503	923	957	1911
	Liquid	3556	705	785	380	1686
7	None	5198	-117	1450	1373	2491
	Air-2	5036	425	1195	520	2896

D. Mission completion

Only one subject was able to complete the first flight day without a cooling vest, and he wore one for the first 2 study days prior to flying without it. All previously acclimatized subjects who failed to complete the first flight day were able to complete their missions on the following day. The two nonacclimatized subjects also were unable to complete the second flight day. First-day failure reason was due to nausea and fatigue with inability to maintain concentration. The most common reason for later failure to complete a flight day was injury due to equipment, especially scalp and face hot spots due to mask fit and wear. These became significant problems by the third and fourth days. Temporary equipment fixes (some of which caused a breach in the mask seal) often were necessary between flights in order to keep subjects flying without terminating the flight day at that point.

FLIGHT PERFORMANCE

A. HIMS-II

Precision in the HAAT maneuver was quantified primarily by the standard deviations of heading (HDG), airspeed (AS), and barometric altitude (BALT). Variables of secondary interest included the standard deviations of vertical airspeed (VSI) and aircraft roll (ROLL). Time on trial was not measured in this

study. Data were compared for flights with and without a cooling vest. The means and standard deviations are displayed in Table 9. Larger standard deviations indicate poorer performance; i.e., more variability in a maneuver requiring precise control. There was no consistent trend observable across the six subjects utilizing single subject analysis.

Table 9. Effect of cooling vest on HAAT performance

Variable	Mean	S.D.	Mean	S.D.	t	p value
Subject 1						
HDG	1.24	0.50	1.23	0.40	0.08	N.S.
B	12.09	7.87	15.53	8.90	2.67	.0099
AS	2.26	0.75	2.41	0.81	-1.[illegible]	N.S.
Subject 2						
HDG	1.47	0.72	1.37	0.59	1.01	N.S.
BALT	13.23	6.46	12.41	6.81	0.80	N.S.
AS	2.55	0.92	2.53	0.76	0.15	N.S.
Subject 3						
HDG	1.28	0.61	1.41	0.66	-1.17	N.S.
BALT	11.03	6.78	10.02	5.86	0.99	N.S.
AS	2.45	0.88	2.36	0.85	0.59	N.S.
Subject 5						
HDG	1.49	1.62	1.44	0.58	0.49	N.S.
BALT	11.39	5.46	12.68	7.89	-1.11	N.S.
AS	2.50	0.73	2.60	0.83	-0.70	N.S.
Subject 6						
HDG	1.80	0.86	1.71	0.77	0.53	N.S.
BALT	13.23	7.95	10.89	6.60	2.04	.0043
AS	2.14	0.67	2.09	0.52	0.48	N.S.
Subject 7						
HDG	1.77	0.98	1.78	0.87	-0.11	N.S.
BALT	14.09	8.97	10.89	5.98	2.59	.0105
AS	2.45	0.92	2.25	0.68	1.51	N.S.

To examine the possibility that the presence of low environmental temperatures may have obscured potentially significant results, an additional analysis was performed using

only HAAT trials with environmental temperatures above 29°C (WBGT). Data were combined for all six subjects to increase sample size. Rectal temperatures were lower when wearing a cooling vest (mean = 37.2) than without one (mean = 37.5). These means were significantly different ($p = 0.001$) as were the variances ($p = 0.0145$). The means of HDG, AS, and BALT, however, did not approach statistical significance.

The precision maneuver was analyzed in the same fashion as the HAAT maneuver except that the variables used were the standard deviations of AS, ROLL, and VSI. Means and t=tests were computed for each variable and subject. None of these comparisons yielded significant differences.

Control movement data

For control movement data, the data quality indices showed that data collected on the first 42 flights were of poor quality due to equipment problems. After the 42nd flight, the faulty potentiometers were replaced and subsequent control movement data were of high quality. All control movement data in this report come from flights 43-108. These data correspond to the last 5 days of flying by subject three and all available flights from subsequent subjects.

In a preliminary analysis, control movement variables were separated by use of a vest. Means are given in Table 10. These data show that there was more movement (FARATE, LRRATE) over longer distances (FADIST, LRDIST) when wearing the cooling vest. These mean differences were significant at the .05 level using the separate variance t=test. Separate variance t=tests were used because the variances were significantly lower for all variables while wearing the cooling vest.

Table 10. Mean control movements variables

Variables	No vest	Cooling vest	T
FARATE	5.44	4.95	2.67
FADIS	221.85	198.58	2.15
LRRATE	5.49	4.45	5.16
LRDIST	221.18	168.98	4.88

Regression analyses indicated that these significant t=tests were based on very small amounts of variance which explained less than three percent at most. The rate and distance measures were highly correlated ($r=.94$) for both fore-aft and left-right

measures. In general, control movements decreased with increasing core temperature ($r=-.135$ to $-.195$) and increased with increasing WBGT ($r=.022$ to $.118$).

Whether statistically significant or not, the magnitude of these control movement results indicated that there was little practical significance in the differences observed.

B. Safety pilot ratings of subject flight performance

Analysis of safety pilot ratings of subject flight performance across all subjects was performed by t-test formulated into two groups: Scores with a cooling vest and without a cooling vest. No significant differences were found ($t=0.15$, $df=99$). A t-test also was performed on the last two subjects for whom higher environmental temperatures were observed, and again no significant differences were found.

PSYCHOMOTOR AND COGNITIVE PERFORMANCE

A. Performance assessment battery (PAB)

The PAB was administered as a measure of cognitive/affective and, to a lesser extent, visual perception performance. Six subtests (not including Mood Scale) were scored for each session by percentage correct and speed of completion, and a combined parameter called throughout was calculated. Mood scale subtest yielded two derived scores, affect (depression) and activation (energy) scales. Factors used in analyzing the PAB subtest data were the following conditions: 1) day, 2) subject number, 3) total time in minutes during which the rectal temperature exceeded 38°C (Hottime), and whether or not the rectal temperature exceeded 38°C during the PAB test period (Htpab), and 4) whether or not the subject wore a cooling vest that day (Cltyp).

Stepwise linear regression analyses comparing afternoon PAB scores with the other factors listed above showed little correlation with whether or not the subject was hot. Wilkinson subtest data by day for all subjects are shown in Figure 13. Typical variation among subjects is illustrated in Figure 14 for the Wilkinson subtest. Wilkinson subtest reaction time across scores are plotted against increased Hottime in Figure 15.

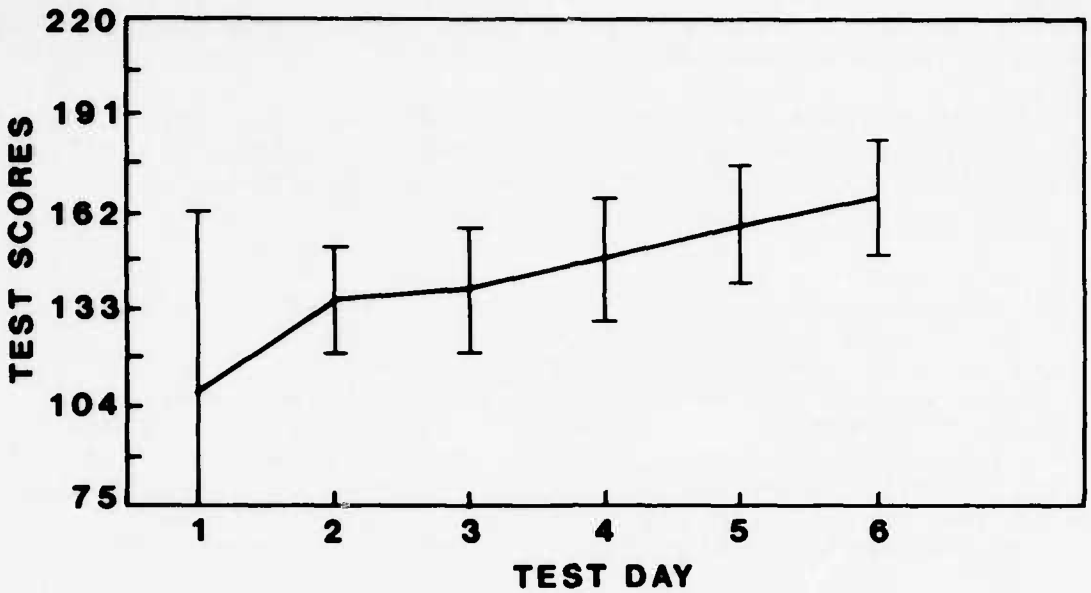

Figure 13. Mean Wilkinson test scores by day of week.

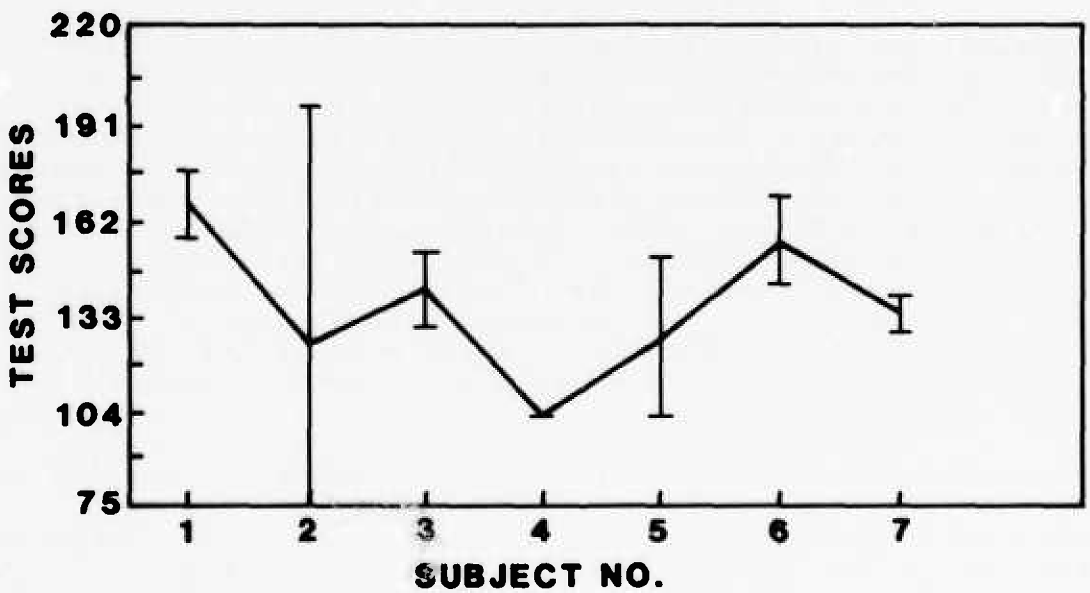

Figure 14. Mean Wilkinson test scores by subject.

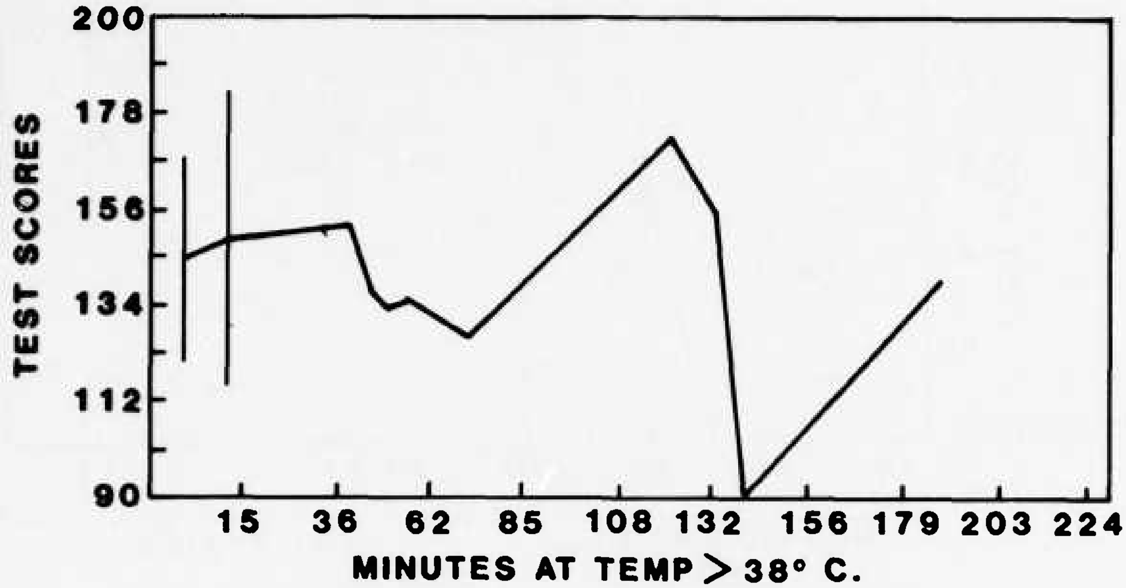

Figure 15. Mean Wilkinson test scores by hottime.

The Mood Scale subtest was analyzed by Measures of Affect (Figure 16) and Activation (Figure 17) in order to assess the level of depression and the activity or energy level of the subjects respectively. Higher affect scores (more depressed attitude) also were found for cases in which the core body temperature exceeded 38°C (Figure 18). Affect scores were found to consistently decrease (less depressed attitude) over the days of testing (Figure 19).

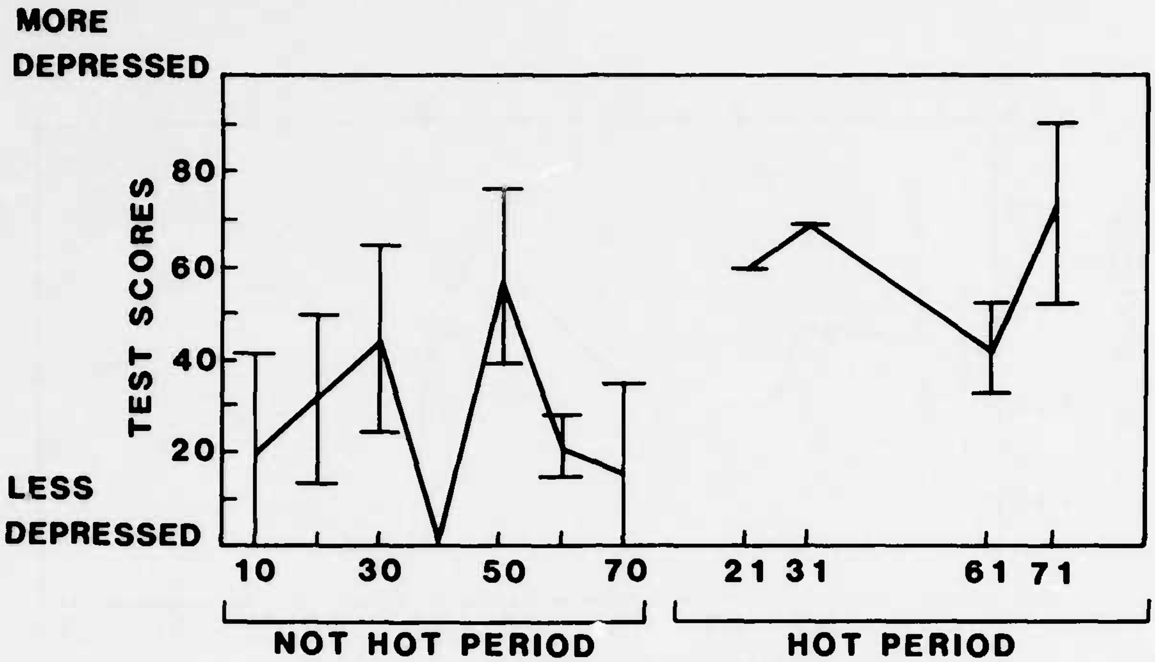

Figure 16. Mean mood scale score versus affect score.

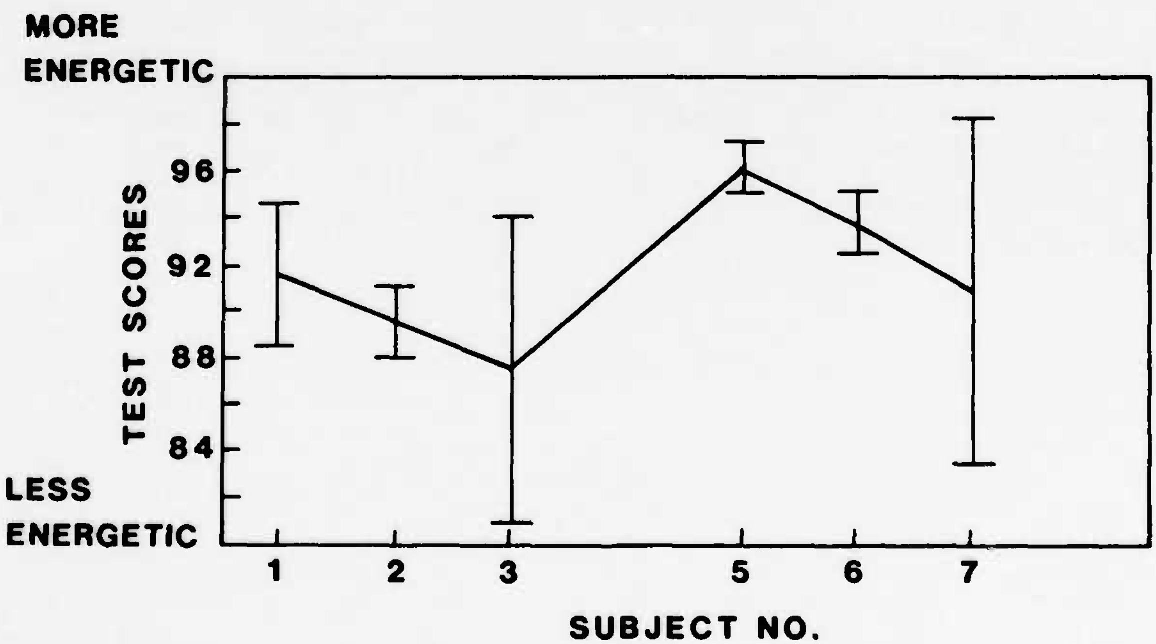

Figure 17. Mean mood scale activation score by subject.

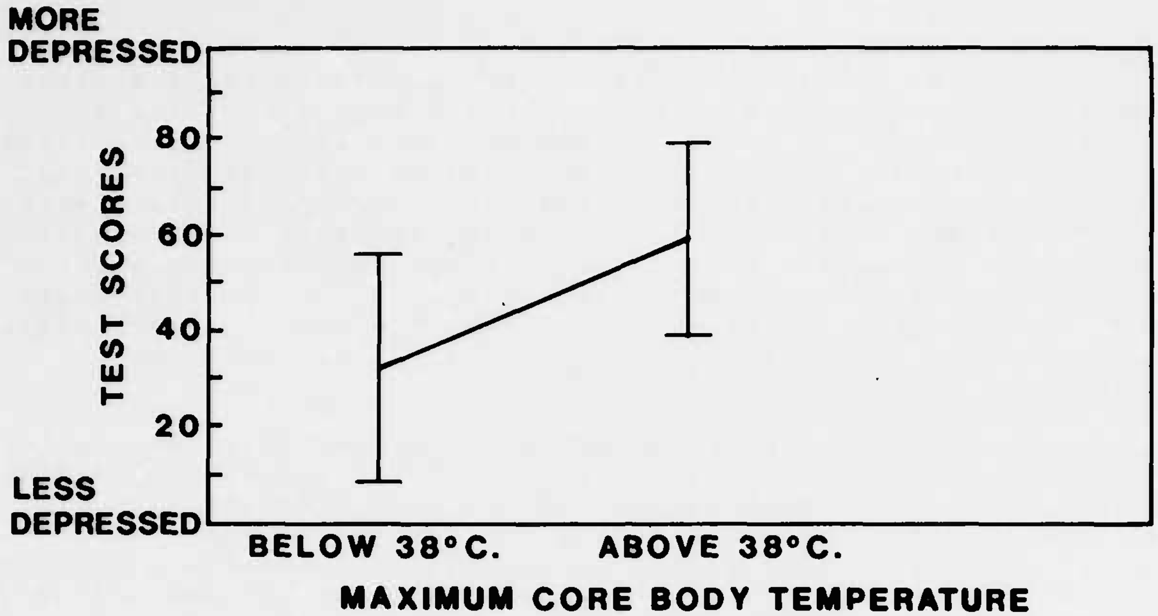

Figure 18. Mean affect score for hot and not hot days.

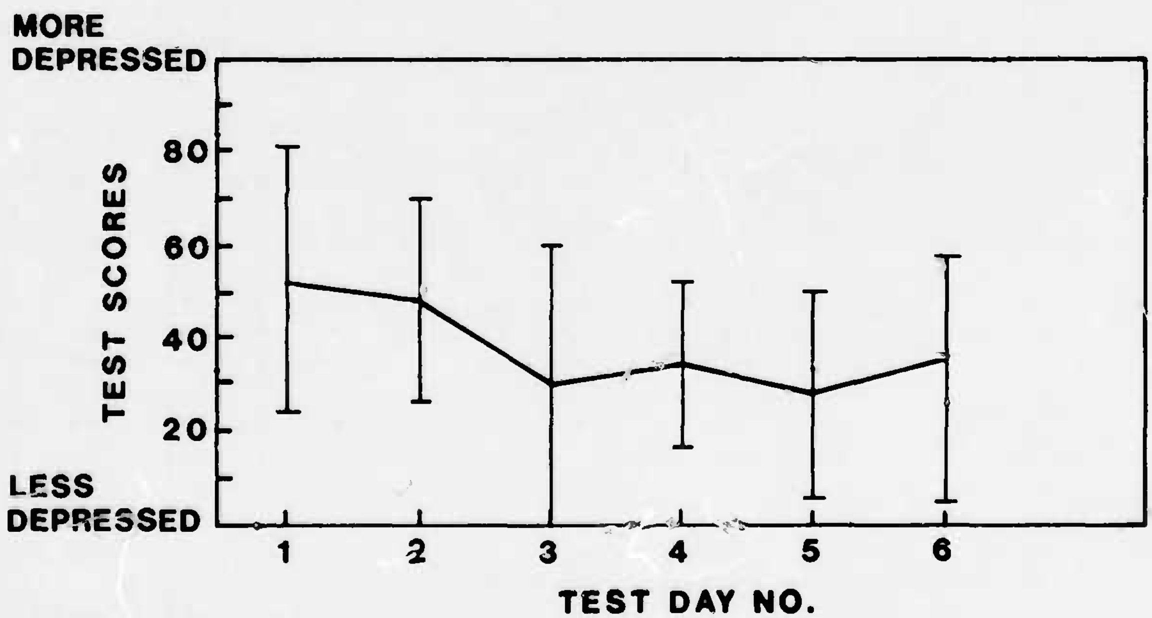

Figure 19. Mean affect score by day of week.

B. ZITA

Graphical analysis of the raw score data revealed a trend toward decreasing scores over days which were identified as practice effect. In order to quantify both linear and nonlinear effects, the factor DAY was represented by a set of orthogonal polynomials according to Winer (1971). These polynomials were analyzed along with the coolant and session data using a multiple regression approach. Each of 11 task/ADT combinations was analyzed separately across all six subjects. To further control the large subject differences observed, the mean for each subject on respective task/ADT combinations was removed prior to regression.

Even with the subject adjustment, the residual intersubject differences contributed significantly to the regression in most of the 11 task/ADT combinations (Table 11). The practice effect had a statistically significant linear component which was evident in higher order tasks (2 and 3). A quadratic component also was present in a lower order task with no ADT and all of the higher order ones. The cubic and quartic components were not statistically significant.

Table 11. Multiple regression results of ZITA data

	Task 0			Task 1			Task 2			Task 3	
	ADT			ADT			ADT			ADT	
Effect	0	2	1	0	2	1	0	2	1	0	2
Subject	**	*	*	ns	ns	*	ns	ns	**	**	ns
Interactions	ns	ns	ns	ns	ns	ns	**	*	**	ns	ns
Session	**	*	*	*	ns	*	**	*	**	**	ns
Practice											
Linear	*	ns	ns	*	*	ns	**	**	**	**	**
Quadratic	ns	ns	ns	**	ns	ns	**	**	**	*	*

Note: * Statistically significant at $p < 0.01$
** Statistically significant at $p < 0.05$
0 = No ADT, 2=2-second interstimulus presentation rate, 1=1-second interstimulus

An examination of the contribution of COOLANT (prior cooling with vest) and SESSION revealed a statistically significant interaction on Task 2 only (all three levels of ADT). There was a statistically significant contribution by SESSION in nine of

the task/ADT combinations; while COOLANT alone was not statistically significant in any. Further examination of the mean scores for the COOLANT by SESSION interaction on Task 2 (Table 12) revealed a consistently larger score in the second session when the cooling vest had not been used in the flights prior to the administration of the ZITA test.

Table 12. Mean session scores (Task 2) by cooling use

		ADT 0		ADT 2		ADT 1	
		Session		Session		Session	
		1	2	1	2	1	2
Cooling Vest	No	197	366	325	627	548	1501
	Yes	197	215	305	312	470	565

PERFORMANCE WITH THE CD ENSEMBLE

Several deficiencies were noted during this study on performance elements associated with the use of the CD ensemble. The butyl gloves lacked tactile sensation and caused difficulty with overhead switch use and with opening latches, especially during preflight (Figure 20). The overboots were difficult to don and had a tendency to catch on the pedals. The garments were bulky and did not allow connectors such as coolant hoses and communications connectors to pass through without breaching the security of the suit. The M-24 mask was noted to have problems with some restricted visibility (when operating in confined areas), fogging of the inside of the mask during temperature changes, increased breathing resistance necessitating frequent changes of the filter, and severe problems with pain and skin erosion requiring padded dressings at mask buckles and over the nasal bridge (Figures 21 and 22). The previously noted inability to perform a Valsalva maneuver with the mask donned was not observed in this study due to the low altitudes flown (less than 1000 feet agl).

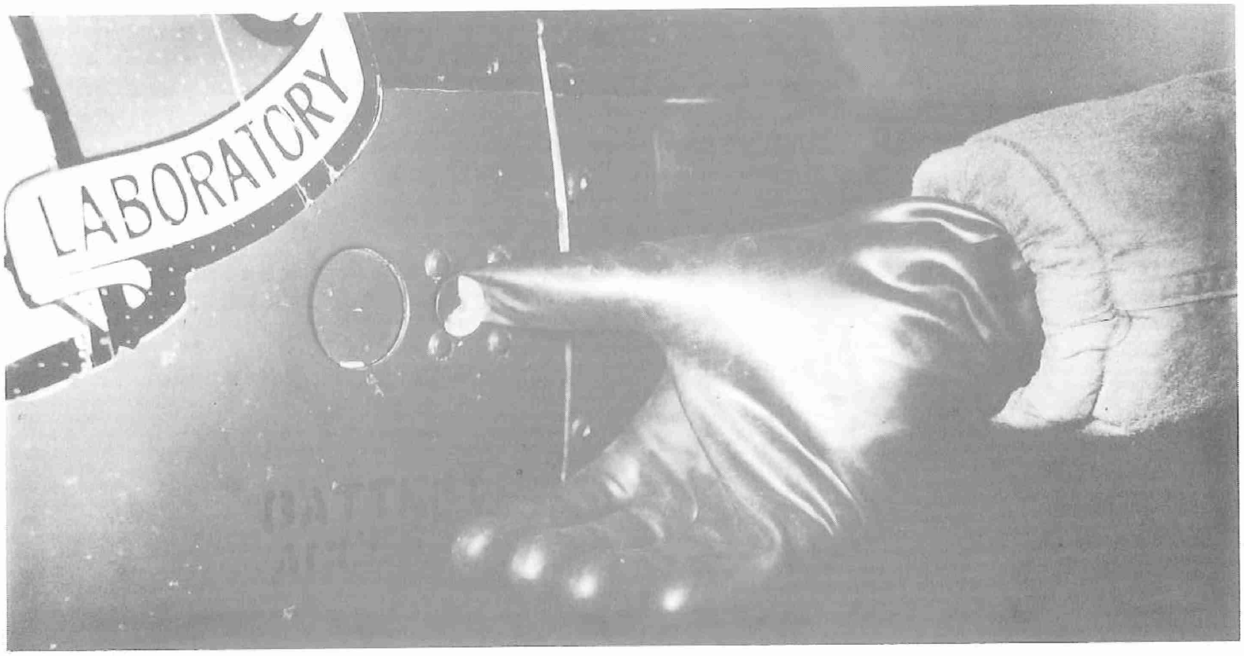

FIGURE 20. Butyl rubber glove problems.

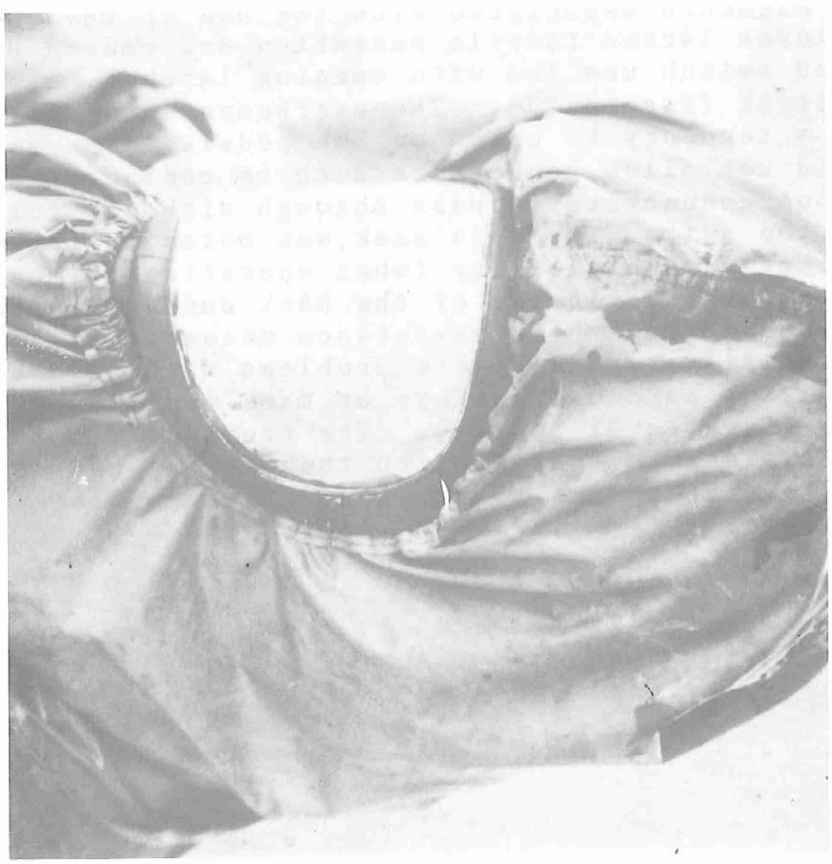

FIGURE 21. Fogging of the M-24 mask.

FIGURE 22. Pressure points from the M-24 mask.

DEBRIEFING COMMENTS

A. From members of study team

Comments from the study team centered on the logistic and maintenance aspects of the various microclimate cooling systems. The two airflow systems were similar in performance, setup, and ease of use. Sufficient airflow was available with both cooling systems tested with the air vest that diversion of some air flow was necessary to avoid a decrease in the rectal temperature of subjects to subnormal ranges. The liquid vest system required tedious setup to eliminate air bubbles and was noted to require frequent maintenance during use. None of the systems were tested with multiple vests in use or with extended length tubing for outside aircraft use.

B. Subjects

Subjects' comments, which were solicited by questionnaire during a debriefing at the end of the last flight day, are contained in Appendix D. All subjects expressed a desire for a redesign of the present CD ensemble for aviation use.

DISCUSSION

PHYSICAL PERFORMANCE

A. Cardiovascular system

Cardiovascular fitness of the subjects was good, although not as good as competitive athletes (See Vander et al., 1984). Heart rates usually seen with exercise, even in acclimatized subjects (Callaham, 1983), were not reached during this study. The rates observed suggested that the work levels involved in piloting the aircraft did not elevate the metabolic rate enough to match the exercise-induced levels found in the literature. The work load of helicopter pilots was estimated to be 125 to 150 watts during flight (Thornton, Brown, and Higgenbottam, 1984).

The subjects' heart rates recorded during use of each cooling vest were poorly correlated with variations in the cockpit temperature. This reflected the ability of the cooling vests to maintain rectal (core) temperature at relatively normal levels in the presence of external heat loading.

The one case (subject five) which did exhibit a significant correlation between heart rate and core temperature may have had the flow-setting on his cooling vest adjusted too low to keep rectal temperature controlled. The correlation between heart rate and cockpit temperature without cooling vests improved at higher environmental temperatures reflecting increased magnitude of the effect over the normal variability of pulse with external stimuli. Also, it was noted that heart rate was correlated significantly with rectal temperature for the same higher temperatures, as would be expected on a physiologic basis.

B. Thermoregulation

In general, the correlation of rectal temperature with cockpit WBGT parallels that of the heart rate noted above. This supports the hypothesis that little internal heat is generated from muscular activity during the flight portions of the study.

A threshold environmental temperature was noted above which subjects experienced increases in rectal temperature to levels exceeding 38°C more than 50 percent of the time. This core temperature has been associated with the onset of decreased performance parameters (Grether, 1973; Wing, 1965). The data supporting the threshold are illustrated in Table 13. The best predictive cockpit temperature for the onset of increased rectal temperature is 29°C. This agrees with both predicted and observed upper boundaries of safe environmental temperatures while wearing the CD ensemble and performing low rate metabolic work (Breckenridge and Levell, 1970; Toner, White, and Goldman, 1981; Berlin, Stroschein, and Goldman, 1975).

work (Breckenridge and Levell, 1970; Toner, White, and Goldman, 1981; Berlin, Stroschein, and Goldman, 1975).

Table 13. Environmental temperature threshold

Actual group	Number of cases*	Predicted group <29 C	>29 C
<38.0 C	1038	79%	21%
=>38.0 C	113	39%	61%

Percent of grouped cases correctly classified: 77%

(* Without cooling vest use)

Above 29° C the thermoregulatory process may be less effective in reducing core temperature (probably associated with the saturation of available heat dissipation mechanisms). There was an increasing risk of heat illness if measures to reduce the body temperature were not taken. The presence of lag times between changes in environmental temperature and the subsequent changes in rectal temperature supported a conservative threshold determination. This occurred since some elevated rectal temperatures recorded at lower cockpit temperatures may represent decreasing environmental temperatures with slower decreases in rectal temperature.

Skin temperatures were widely variable and poorly correlated with rectal temperature trends. Previously published criteria for detecting the onset of significant heat stress based on convergence of mean skin temperature and rectal temperature (Pandolf and Goldman, 1978) were not useful under these experimental conditions. The controlled environment of the laboratory is not available or necessarily applicable in an aircraft cockpit. This lack of usefulness led to the abandonment of skin convergence criteria for assessing heat loading during field tests.

C. Fluid balance

Table 8 reflects that each subject sustained some loss of body weight early in the first days of the study. Relatively small urinary outputs in this period suggested fluid shifts and dehydration as a mechanism for this loss. Subjects experienced

recovery (reexpansion of fluid volume) after the third day, and usually reached initial weights by the sixth day. Regaining of initial body mass was associated with the use of cooling vests, although not necessarily causally. Loss of muscle mass from relative inactivity (no active exercise program) could account for any net weight loss recorded during the week.

The daily weights of uniforms indicated that sweat loss and evaporation through the CD ensemble were a significant part of the heat dissipation mechanism. The loss of weight from respiratory exhalation was not measured, but it was assumed to be relatively insignificant in the humid environment of the test location.

Twenty-four hour fluid intakes needed to maintain adequate hydration averaged only approximately five liters compared to previous estimates of up to one liter per hour. This difference suggested that present fluid intake guidance may not be generalized for all hot environments and could cause overhydration and water intoxication. It is suggested that urinary output sufficient to allow voiding every 4 to 6 hours was a better field monitor of proper fluid intake. Shorter intervals are appropriate as environmental temperature increased to ensure proper hydration monitoring. This fluid doctrine would be identical in effect to forced hydration in the hot, dry environment of the desert, but would allow individual differences in less hostile situations.

D. Mission completion

Subjects with prior heat acclimatization in MOPP IV and without microclimate cooling were able to complete all assigned missions after the first day, but the last two subjects (without acclimatization) were not able to complete all four missions until the fifth day. As indicated earlier, there was no significant correlation of prior acclimatization with either heart rate or rectal temperature even though the WBGT was significantly higher for the nonacclimatized subjects. This may reflect rapid acclimatization of the later subjects (who already were in excellent physical condition). Significant differences in average heart rate and/or rectal temperature were not seen in either group, so the acclimatization process may include psychological as well as physiological factors. Psychological factors may account for the reported nausea on the first day without a cooling vest which occurred to all but one subject.

PSYCHOMOTOR AND COGNITIVE PERFORMANCE

A. Performance assessment battery

The stepwise multiple regression analyses comparing the afternoon scores with all other factors show, in general, little relation to heat loading.

Learning effects were demonstrated in Score versus Day upward trends, particularly in the Wilkinson subtest (see Figure 13). This improvement over test session trend was less noticeable in the Mast 6 and Logical Reasoning subtests. These learning curves compare closely in slope and absolute value to those measured in a separate PAB validation study of unstressed Army aviators (Edwards, 1984). Wide variation also was demonstrated between subjects in performance on some subtests, particularly the Wilkinson and Serial Addition. Logical Reasoning, Matrix, and Mast 6 were not divided so widely. The variation in these curves also compared to the PAB validation study curves.

The Wilkinson subtest showed the most significant decrement in performance with increased hot time, with Probe Memory, and Mast 6 also demonstrating a smaller decrement. The Wilkinson tends to be a fatiguing test with a long duration, so it may be a better measure of fatigue and decreased concentration.

Interesting results were obtained from the Mood Scale. The Affect (depression) Scale shows a definitely higher score (i.e., more depressed) on days in which maximum core temperature rose above 38° C. There was less depression across subjects as the week progressed, which was not an expected result. This could be an anticipation of the approaching end of the stress period, an increase in comfort level with the daily routine, or a physiological effect of heat. The Activation (energy) Scale showed a moderate baseline variation between subjects, but did not change significantly across days or days grouped by hot and not-hot.

Of the PAB subtests, the Wilkinson four-choice reaction time test was the only one of the nonmood scale tests that was sensitive to heat stress (slower reaction time scores after longer exposures to heat stress). The Mood Scale, in particular the Affect Subscale, also showed differences in the scores of subjects who were tested on hot versus not-hot conditions. The subjects were depressed under heat stress and concentration was decreased as reflected by longer reaction time scores.

B. ZITA

The observed subject differences were expected, as was the practice effect. Tasks 0 and 1 were very easy, Task 2 was more difficult, and Task 3 was very hard for most subjects.

Closer examination of the scores between sessions showed that subjects generally scored higher (exhibited poorer performance) after flying than before. Aviators did not significantly change their scores on Task 2 after flight if they had worn a cooling vest during flight. This finding must be tempered, though, by the knowledge that there were three times as many runs of Task 2 as there were of the other three tasks in the ADT 0 condition. It is possible that more runs of the other tasks could have resulted in a statistically significant interaction for them as well.

FLIGHT PERFORMANCE

A. HIMS-II

The HAAT maneuver was flown first in each flight which suggested that heat stresses built up during each flight would occur after the maneuvers were completed. This effect would be most demonstrable for the first flight since later flights would follow heat loading conditions on the ground during throughflight checks. No rectal temperature above 38.4°C was noted during the HAAT maneuver in the study. With the levels of heat stress observed, few analyses of aircraft control variables reached statistical significance. However, it was observed that the two subjects with high rectal temperatures (subjects 6 and 7) did show significantly better control of barometric altitude when flying with the cooling vest than when flying in similar environmental conditions without it. None of these results had sufficient consistency across subjects and conditions to indicate any operational significance. It may be concluded that the well learned psychomotor skills of graduate aviators appeared to be resistant to the levels of heat stress observed during this study.

The precision maneuver was analyzed in the same fashion as the HAAT. Means and t-tests showed no significant differences in comparisons of each flight variable with subjects or other factors. The lack of strong effects of heat stress on this maneuver may be due to several factors: (1) The level of heat stress produced during this study may have been too moderate; (2) subjects were sometimes withdrawn from a flight prior to performance of the precision maneuver due to medical effects (nausea or fatigue) since the maneuver occurred last in the flight profiles; and (3) the scheduled total of 24 flights per subject was not completed which reduced available data. Thus, the precision maneuver was insensitive to any degradation of

performance which the aviators may have experienced under the conditions observed.

Control movements did show statistically significant effects of fairly small magnitude. These differences are interesting, but probably do not have practical implications for the use of cooling vests.

B. Safety pilot ratings of subject flight performance

No significant differences in safety pilot ratings of subject performance were found between cooling and noncooling days for any subject. There were several conditions which likely contributed to greater variances and lack of significant difference in performance across the cooling and noncooling conditions. (1) Lack of sufficient heat stress throughout the study; (2) the fact that five different safety pilots rated the subjects performance on various flights, inducing a certain amount of rater error even though the tasks and rating schemes were standardized as much as possible; (3) the flight performance rating scheme used was not sensitive to differences that may have been present; and (4) the overlearned activity of flying was resistant to decrement.

CONCLUSIONS

PHYSICAL PERFORMANCE

A. Cardiovascular system

The subjects were in excellent physical condition. Heat acclimatization prior to participation was accomplished in the first four subjects studied and resulted in less nausea and fatigue during the first 2 days of flying than the unacclimatized subjects. No subject exhibited sustained increases in heart rate above 120 beats per minute. The rate for noncooled flights was correlated with the cockpit temperature and exhibited variability consistent with autonomic input from the physiologic and psychologic stresses of flight.

B. Thermoregulation

A threshold environmental temperature was noted above which noncooled subjects experienced increases in rectal temperature to levels exceeding 38°C. This 38°C core temperature had been associated previously with the onset of decreased performance. The lower bound of environmental temperature (WBGT) for the onset of increased rectal temperature was 29°C. This agreed with both predicted and observed upper bounds of safe environmental

temperatures while wearing the CD ensemble and performing low-rate metabolic work.

No subject wearing a microclimate cooling device experienced significant elevation of rectal temperature at any environmental temperature observed.

C. Fluid balance

Analysis of daily blood samples and urine collection did not reveal significant trends. Twenty-four hour fluid intakes needed to maintain adequate hydration averaged only approximately five liters compared to previous estimates of up to one liter per hour. This difference suggests that present fluid intake guidance may not be generalizable to all hot environments and could cause overhydration and water intoxication. It is suggested that urinary output sufficient to allow voiding every 4 to 6 hours would be a better field monitor of proper fluid intake. Shorter intervals were appropriate as environmental temperature increased to ensure proper hydration monitoring.

D. Mission completion

Nausea was a factor in limiting the number of complete missions performed on the first day for all but one subject. This was independent of prior acclimatization and may reflect psychological adaptation to flying in MOPP IV. Acclimatized subjects were able to perform full flying schedules on the second day without difficulty, but nonacclimatized subjects required 2 days to reach maximum flight day duration.

PSYCHOMOTOR AND COGNITIVE PERFORMANCE

A. Performance assessment battery (PAB)

The Wilkinson (four-choice reaction time) and Mood Scale subtests of PAB appear to be sensitive to heat stress in aviators. The Wilkinson scores show a wide variation in individual performance, but in spite of this, show decrement in performance when the hot-time increases. Wilkinson is considered to be a measure of "level of concentration" and is influenced by such factors as fatigue.

The Mood Scale shows that the effect of heat is to depress the aviator. Though the Mood Scale scores indicated the subjects were less depressed as the test week progressed, the depression scores clearly were higher in the group in which temperatures rose above 38°C.

B. ZITA

Based on the results of Task 2 of the ZITA test after several consecutive flights, aviators dressed in the MOPP IV CD ensemble were better able to perform tracking tasks if they had been cooled during the flights.

FLIGHT PERFORMANCE

A. HIMS-II

The moderate degree of heat stress occurring during the HIMS-II measurement periods did not appear to affect the precision of aircraft control. Control movement effects were extremely small. Thus, the temperatures seen were not sufficient to cause any differences between pilot performance with and without a microclimate cooling vest during the recorded maneuvers. Justification for cooling vest use under the conditions monitored must be on the basis of physiologic and psychologic effects as well as mission completion and not on the basis of flight performance differences.

B. Instructor pilot (IP) ratings of subject performance

Most low performance noted by the subject ratings occurred during the NOE portions of flights, particularly when the subject was navigating. Subjects were penalized if they had to return to a known point on the NOE course. This occurred more than once on many NOE flights, thus causing a lower performance rating and indicating potential problems with navigation skills under the study conditions. Overall, the ratings and comments from the safety pilots indicated that all subjects could fly safely in MOPP IV equipment and generally perform to ATM standards under the environmental and operational conditions of the study.

ENSEMBLE PERFORMANCE

Several problems were noted by the subjects during the study with the currently fielded MOPP IV gear for aviation use:

1. The mask fogs on the inside during rapid temperature changes (altitude).

2. The breathing resistance of the M-24 mask filter increases rapidly during humid weather conditions.

3. The mask does not allow drinking without loss of seal integrity.

4. Hot spots are common limiters of wear duration of the mask due to buckles, the nose piece, and the incorrect use of skull caps.

5. The M-24 mask reduced peripheral vision and required extra effort during confined area operations.

6. The butyl gloves critically reduce tactile sensation and catch on aircraft structures during preflight check procedures.

7. The boots catch on trim pedals, but were not observed to slip or catch on the aircraft during preflight check procedures.
8. The suit has no provision for umbilical cables; e.g., communications cords or cooling hoses.

All subjects reported a subjective increase in work capacity while wearing a microclimate cooling device. Each expressed a desire for the implementation of chemical protective gear designed specifically for the needs of aviation.

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APPENDIX A

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Division of Mettler Instrument Corporation
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Hightstown, NJ 08520

Norman K. Walker Associates, Incorporated
19564 Club House Road
Gaithersburg, MD 20879

APPENDIX B

INFORMED CONSENT DOCUMENTS

VOLUNTEER PARTICIPATION AGREEMENT

I, ,SSN , having attained my eighteenth (18th) birthday, and otherwise having full capacity to consent do hereby volunteer to participate in a research study at the US Army Aeromedical Research Laboratory and at Highfalls Stagefield, entitled "Heat Stress Effects of the Aircrew Chemical Defense Ensemble," under the direction of Francis S. Knox, Ph.D., at the US Army Aeromedical Research Laboratory (USAARL).

The implications of my voluntary participation; the nature, duration, and purpose; the methods and means by which it is to be conducted; and the inconveniences and hazards which may reasonably be expected have been explained to me by Dr. Knox, principal investigator, and are set forth on the attachment of this agreement, which I have initialed. I have been given an opportunity to ask questions of Dr. Knox concerning this investigational study, and my questions have been answered to my full and complete satisfaction.

I understand that I may at any time during the course of this study revoke my consent and withdraw from the study without prejudice. However, I may be required to undergo further medical examinations, if in the opinion of the attending physician such examinations are necessary for my health and well-being.

My point of contact for questions regarding legal rights is MAJ C. Ivey, 3819.

Please indicate who you would like us to contact in the event of emergency:

Name: Phone:

My family's point of contact for emergency messages to me during the study is:

Duty hours: 255-6864,
Off-duty hours: 255-6936, CQ, USAARL

Signature: Date:

I was present during the explanation referred to above as well as the volunteer's opportunity for questions and hereby witness his/her signature.

Signature: Date:

PRIVACY ACT STATEMENT

1. AUTHORITY

- Section 301, Title 5, United States Code.
- Section 3101, Title 44, United States Code.
- Section 1071-1087, Title 10, United States Code.
- Executive Order 9397.

2. PRINCIPAL PURPOSE

The purpose for requesting personal information is to provide:

- Various types of data needed to satisfy the scientific objectives of the study.
- Minimum information necessary should you require medical treatment at any future time for a condition proximately resulting from your part in this research study.
- Minimum information so that steps can be taken to contact you later should it be in your best interests.

3. ROUTINE USES

- This information may be used to:

    1. Implement health and communicable disease control program.
    2. Provide full documentation of research studies.
    3. Conduct further research.
    4. Teach.
    5. Compile statistical data.
    6. Adjudicate claims and determine benefits.
    7. Report medical conditions required by law to other federal, state, and local agencies. There is a possibility that authorized representatives from the Food and Drug Administration and US Army Medical Research and Development Command may periodically inspect these records.

- This information may be used for other lawful purposes, including law enforcement and litigation.

- Even though permitted by law, when possible, this personal data will not be released without your consent.

4. MANDATORY OR VOLUNTARY DISCLOSURE AND EFFECT ON PERSON NOT PROVIDING INFORMATION.

Disclosure of requested information is voluntary. If the information is not furnished, or is not available from other sources, voluntary participation in this study may be prevented.

I understand that:

- A copy of the Volunteer Consent Document, together with a copy of this form, may be placed in my health records as evidence of this notice.

- Additional copies may be retained permanently by the investigator and by the US Government.

I have received, or have declined to accept, a copy of the Volunteer Consent Document and a copy of this form, which I may keep.

Date Signature

VOLUNTEER AGREEMENT
(ATTACHMENT)

PURPOSE

You are being asked to participate in a research program entitled: "Heat Stress Effects of the Aircrew Chemical Defense Ensemble" to assess the ability of US Army aviators to perform mission-oriented tasks in the chemical defense environment. Standard aviator day schedule will be followed for an extended and continuous period while wearing the Mission Oriented Protective Posture IV (MOPP IV) ensemble in order to replicate the situation likely to be faced on the integrated battlefield of the next war.

PROCEDURE

Prior to your participation in the study, you will be asked to fill out a medical history questionnaire and will be given a physical examination by a flight surgeon. The examination will include tests of your respiratory and cardiovascular systems by exercising on a treadmill while you are being monitored. Your body fat will be estimated by the standard caliper test such as is used in the height-weight standards determination. In addition, you will be expected to complete two periods of 50 minutes of outdoor activity involving moderate physical exercise while in MOPP gear during each of the 7 days prior to the week of actual flying. This time allows you to become fully acclimatized to the gear and will improve your heat tolerance. These exercise periods should be separated by 10-minute rest periods and may be accomplished at any convenient site.

For the next 6 days you will stay at Highfalls Stagefield to simulate extended, continuous operations. You will live under field conditions and wear MOPP gear continuously (except during shower and clothing changes): MOPP IV during the flying day and MOPP I during the evening and night. You will be asked to fly rotary-wing aircraft and perform standard maneuvers as described in Aircrew Training Manual TC 1-135 (DA, 1981). As an experimental subject, you will be asked to fly approximately 6 hours per day for 6 days in the MOPP IV ensemble. On some of the days, you will be outfitted with a cooling vest under the MOPP gear and on other days you will not use the cooling vest.

At the beginning of each flight day, you will be connected to monitoring equipment which will monitor heart rate, respiratory rate, skin temperature, and internal temperature via three chest electrodes, four skin temperature sensors, and a flexible rectal thermometer. These will allow us to continuously monitor your body's reaction to the environment, and to

intervene, if necessary, at any signs of developing medical problems. Blood will be taken from your arm each morning and evening to check on your physical condition, and your urine output will be collected for analysis.

Additionally, testing of your ability to think rationally and to perform tasks requiring fine coordination will be carried out intermittently during the course of the experiment. Other safety precautions also are utilized. You will be monitored for fluid intake and output and corrective intake will be encouraged if not adequate for the measured environment conditions. Your diet will be Army field rations with adequate salt replacement for your losses. The aircraft safety pilot will wear standard US flight clothing. A medical observer and a monitoring equipment operator will be on board during all flights as members of the research team. A medical monitor (flight surgeon) will be on call by radio to provide immediate medical advice to the medical observer and flight crew, if needed, and will be standing by at the stagefield with complete resuscitation equipment and an emergency medical team.

RISKS

Although there are risks associated with procedures such as drawing blood (such as developing a local swelling from leakage of blood under the skin or rarely of developing local inflammation of the vein called "phlebitis"), the most important medical risks associated with this study are those of heat-related illness; i.e., heat exhaustion and heat stroke. Mild forms of heat exhaustion can occur with high ambient temperatures and insufficient water intake, so these will be carefully monitored during the study. Heat stroke is rare and would not be expected to happen in this study; but it could happen to a susceptible individual with water and/or salt depletion with high levels of exercise and ambient heat. A brief description of these conditions is as follows:

Heat exhaustion

This disorder can be manifested in two ways depending on whether the condition developed rapidly (in hours) or more slowly (over several days). The rapid onset form is called water-deficient heat exhaustion and is caused by inadequate replacement of water losses due to prolonged, excessive sweating during severe heat exposure. It usually presents a picture of thirst, fatigue, decreased urine production, and increasing body temperature and can progress in severity to heat stroke as described below. The slow onset form is called salt-deficient heat exhaustion and is caused by inadequate replacement of salt lost over several days to weeks of profuse sweating. It presents a picture of increasing fatigue, muscle cramps, inappropriate

giddiness, nausea (sometimes with vomiting), and in severe cases, circulatory failure and shock.

The treatment of these conditions is based on prevention and early recognition of symptoms and signs. An adequate intake of water at all times during exposure to heat stress, including before and after work loads, will prevent most water-deficient symptoms. The salt content of field rations usually is sufficient to balance sweat losses and prevent the salt-deficient form of heat exhaustion as well. In the event that heat-related illness does develop, the treatment includes removal of the subject from the heat stress, rest in a cool environment, and administration of fluids. The person should be kept cool until his heat regulating system is back in balance. If the signs and symptoms are rapidly worsening, the illness is treated as heat stroke which is discussed below.

Heat stroke

This is a serious illness in which the body loses its ability to regulate internal temperature and can lead to death. This disorder seems to have two modes of onset as does heat exhaustion. The slow form is characterized by loss of the sweating mechanism with rapid, severe rise in internal temperature to greater than 40.6 deg C (105 deg F). The slow form is associated with salt depletion and chronic exposure to severe heat stress. The more rapid form develops while sweating is still active, but the internal body temperature is rising to dangerous levels. Both forms show a picture of progressive signs and symptoms including inappropriate elevated mood, restlessness, aggressive behavior, dizziness and numbness, loss of coordination, mental confusion, disorientation, and finally coma. Death follows if the temperature is not reduced in a short time and brain damage can occur if the coma is prolonged.

Treatment of heat stroke is similar to that for heat exhaustion, but is more aggressive in terms of reducing the body's internal temperature. Ice packs are placed at the back of the neck, the armpits, and the groin to cool the blood. The subject is wet with water and air is circulated over him to increase cooling by evaporation. Drugs may be needed to reduce shivering which can develop and to control the blood pressure. In the most serious cases, full resuscitative measures may be necessary to maintain circulation while bringing the body temperature down to a safe range.

It is expected that you will experience some degradation of your normal performance due to heat stress. The safety pilot will observe constantly your performance and will not allow deterioration to reach unsafe levels.

Although you will be stressed and uncomfortable during this study, we have established safety limits which will cause the experiment to be halted if they are reached. By monitoring heart rate, respiration, and skin and rectal temperatures, and comparing these readings with the established limits, we will be able to stop the experiment at a point which will minimize the risk to you in this setting.

Date Initials

USAARL TREADMILL CONSENT FORM:
PERMISSION TO PERFORM TREADMILL STRESS TEST

In order to participate in clinical research, I hereby consent to engage in maximal treadmill exercise stress testing to determine the physiologic capacity of my heart, circulatory system, and lungs.

The test which I will perform will utilize a treadmill with the amount of required physical effort increasing each 3 minutes. The increase in effort may include an increase in the speed of walking/running as well as an increase in the incline. This exercise will continue until the physician terminates the test or until I experience extreme fatigue, shortness of breath, chest discomfort, lightheadedness, or other bothersome symptoms. I understand that I may choose to stop the test at any time. During the performance of the test my pulse, blood pressure, oxygen utilization, and electrocardiogram will be monitored constantly by trained personnel, and a physician will be in attendance at all times.

There exists the possibility that certain changes may occur during the test. These include rise or fall in blood pressure, fainting, serious disorder of the heartbeat rhythm requiring immediate therapy, and in very rare instances, heart attack. I understand that death is a recognized complication of treadmill stress testing, but occurs extremely rarely. I understand that every effort will be made to minimize any complications by continuous observation during treadmill stress testing and by the availability of equipment and personnel designed to deal with unusual situations which may arise.

The information obtained will be treated as privileged and confidential and will not be released to any person without my express written consent. This test will be performed as part of a USAARL scientific investigation; the information will be used only for statistical and scientific purposes. A copy will not routinely be placed in my permanent medical record nor will this information be released to any third party without my express written direction.

I have read the foregoing and understand it. Any questions which have occurred to me have been answered to my satisfaction.

Typed or printed name:

Signature: Date:

Witness:

UNCONDITIONAL CONSENT FOR USE OF PICTURE AND SOUND

The United States Government is granted the right to use, to the extent and for the purpose it desires, any pictures (still, motion, those transmitted via TV, or recorded on video tape or otherwise) and sounds (vocal, instrumental, or otherwise) whether used together or separately, taken or recorded by or on behalf of the US Army Aeromedical Research Laboratory.

(DATE) (SIGNATURE)

(HOME ADDRESS)

(MILITARY ADDRESS)

Above consent obtained by:

(SIGNATURE)

APPENDIX C

SUBJECT RATINGS

SUBJECT RATINGS

Task: Low level (Subject navigating)

1. Subject could not find LZ = 5
2. Subject navigated within 500 m of LZ = 3
3. Subject navigated within 300 m of LZ = 2
4. Subject found LZ within 100 m = 0

Task: NOE (Subject flying)

1. Safety pilot (SP) had to take control of aircraft for safety purposes (tree, wire, etc.):

   ----------- x 5 = ------- .
   # incidents score

2. SP had to repeat directions/instructions after initial acknowledgement:

   ----------- x 5 = ------- .
   # repeats score

Task: NOE (Subject navigating)

1. Subject navigated within 100 m of course:

   x 3 = .

   # times outside 100 m corridor score

2. x 3 = .
   # returns to known point/course score

Task: Ground control approach

1. Maintains assigned heading within:

degrees	0	2	5	10	15
score	1	2	3	4	5

2. Maintains assigned altitude within:

feet	0	50	100	150	200
score	1	2	3	4	5

Task: Instrument Landing System approach

1. Maintains KIAS = 90 kph):

knots	0	5	10	15	20
score	1	2	3	4	5

2. Maintains altitude within 100 m during all segments:

feet	0	50	100	200	300
score	1	2	3	4	5

3. Remains within full scale deflection of CDI & glideslope:

	1 dot	2.5 dots	Within FSD correction <= 15 sec	FSD w/o correction > 15 sec	FSD w/o
score	1	2	3	4	5

Task: Route RECON

1. Noted terrain which could influence movement along route:

   Yes -----   No -----

2. Noted possible construction sites or obstacles:

   Yes -----   No -----

3. Noted obstacles (natural or constructed):

   Yes -----   No -----

APPENDIX D

SUBJECT DEBRIEFING

DEBRIEFING QUESTIONNAIRE
1984 HEAT STRESS STUDY

(Listing of test subject answers)

A. What are your feelings about tent quarters?

1. Adequate.
2. OK and necessary for accurate results.
3. Tent should be oriented for cooling.
4. Openings should be oriented to wind for cooling.
5. No problem. Feel that MOPP I was not necessary.
6. Very appropriate.

B. How did you feel about Meals Ready to Eat?

1. No problem.
2. Better than C rations. Breakfast would be nice.
3. No problem.
4. MREs are a fact of life. Lack of breakfast type MRE caused to eat less in the morning.
5. OK for the first 3 days, then monotonous. Lack of breakfast made a negative impression.
6. The variety and content were satisfactory.

C. Any effects from the liquid noon meal?

1. Helped.
2. The electrolyte solution brought me around. I need more than water.
3. No bad effect.
4. No bad effect.
5. I was hungry from 1030 hrs on for the entire day.
6. I looked forward to the cool liquid.

D. If you had a choice, would you carry:

Two canteens of electrolyte solution.	2,4
Two canteens of water.	---
One canteen of each of the above.	1,3,5,6

E. How would you change the flight profiles?

1. Increase the task load; e.g., I wasn't responsible for performance planning, radio calls, fuel management, etc. Additionally, the missions themselves did not incur the same workload as Aeroscout missions.

2. As an Aeroscout, I must control five Cobras, call TAC air, call artillery, and make spot reports in addition to flying and navigation.
3. Devote less time to the test maneuvers and more to NOE.
4. Scout and attack profiles should be added.
5. Remove the research test maneuvers.
6. Include mission planning (weather, PPC, tactical briefing).

F. What is your feeling about the length of the flight day?

1. An awfully long day. No aviation commander can expect to operate in MOPP IV for 10-12 hours a day.
2. Acceptable; normal.
3. Realistic.
4. Exactly what I expected.
5. Long. Doors closed are definitely difficult to cope with.
6. Extremely realistic and taxing.

G. Do you feel effects from the restrictions of wearing MOPP gear around the clock?

1. I feel weaker. Physical condition has deteriorated.
2. I feel temporarily weak, but no long term effects.
3. I didn't exercise since I thought it might influence test.
4. A little weakened.
5. Managed to run 10 miles this week, but it is a far cry from my usual 25-35 miles.
6. I'm looking forward to getting back to regular exercise.

H. What are your impressions of the MOPP boots, gloves, and garment?

1. Boots were cumbersome and the strings catch on things like antitorque pedals. Gloves allowed no small work to be done. I'm also concerned about what would occur and what my hands would look like in a postcrash fire.
2. Boots difficult to don and gloves lose dexterity. Hands wrinkle a lot during the day from sweating.
3. Gloves do not allow identification of switches.
4. Boots catch on aircraft. Sizes are too large. Suit too hot.
5. The sun shining through the windshield heats the gloves. The components don't breathe and control touch is lost.
6. The gloves absorb and retain too much heat. When the suit became saturated, the charcoal leaked everywhere.

I. What are your impressions of the mask?

1. Too many straps, not enough sizes; face plate scratches, clouds, and distorts; extremely uncomfortable; unable to use sun visor, and the pop-in screen is trashy.
2. Facepiece is crummy; vision distorted and peripheral vision is poor. No capability for protected drinking.
3. Resistance to breathing too high. A forced air system needed.
4. All-around too uncomfortable.
5. It is not designed for flight. Creates hot spots which detract from mission. In strong light, can't darken glass.
6. After 3 hours it is unbearable. You can't drink through it; very painful; and you have to fight for breath in it. It is annoying and taxing.

J. What were your impressions of the cooling vests?

1. Provided adequate cooling. Slightly cumbersome in the back and hot to wear when not connected to the system.
2. Vest better than without. Air to mask necessary. Need walk around cooling, too.
3. Outstanding.
4. Worked better than I expected.
5. Very good. Fighting in a chemical environment and hot climate will be suicidal without it.
6. Fantastic; light and comfortable.

K. Any problems and/or suggestions for the entire ensemble?

1. NBC suits are not made for a 29" waist, 32" chest, 32" inseam on a 69"/130 lb frame!
2. Very time-consuming to don. Redesign, rework from scratch.
3. Change the mask.
4. Hot spots a problem. I think the head and crotch are the most important places to cool.
5. Ensemble needs to be lighter.
6. Difficult to don in a timely manner. Need to train in it more hours a day and weeks at a time so more people will be aware of its shortcomings. Need the aircooled vest and go to a helmet face shield ensemble that seals at the neck.

L. Any additional comments?

1. None.
2. None.
3. None.
4. Preflight should be divided between the two pilots.
5. If this study does not cause changes, I will be extremely

disappointed and upset to have my body put through a very tough experience for no good reason.

6. I feel very fortunate to have been able to participate and I have become a firm believer that we could survive if we had the proper gear.

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